

NASA Armstrong Flight Research Center



Aerostructures X-Plane Airworthiness Guidelines and Best Practices

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NEW AVIATION HORIZONS



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Understand Airworthiness

- ... As applicable to flight research
- **Definition**
 - NASA Procedural Requirements 7900.3C
 - “The capability of an aircraft to be operated within a **prescribed flight envelope** in a **safe manner**.”
- **X-planes and research aircraft are not normally fleet “certified” operational systems (neither FAA or DoD)**
 - NASA provides own airworthiness
 - Each aircraft has unique requirements, research, mission, flight envelope, airframe and systems, etc.
- **Tailor design and airworthiness methodology to meet unique research/mission requirements**
 - Designs adequate (not perfectly optimized) for experiment needs
 - Multiple paths to airworthiness
 - Higher unmitigated risk → additional mitigation is possible (testing, instrumentation and monitoring, shorter life, more inspections, etc.)

Static Structures



- **Big picture: Confidence in strength & confidence in loads**
- **Many approaches to design, test, and operate "one-of-a-kind" aircraft or to modify certified aircraft**
- **Guidelines for entire vehicle or only for certain area(s)**
- **Guidelines are starting points for tailorable approaches to address strength and loads**
 - Certification approach from Mil-A-8860
 - NASA AFRC Approach #1 – “No-Test & No-Data” Factor of Safety
 - NASA AFRC Approach #2 – “Test & Data” Factor of Safety
 - NASA AFRC Approach #3 – “Test & No-Data” Factor of Safety
 - Other approaches...

Static Structures (Cont.)



- **FAA/DoD Approach for Fleet Certification**

- Factor of Safety = 1.5 FS on ultimate
- Proof Test = Dedicated, full-scale, equivalent article to 150% DLL
- Instrumentation = Fully instrumented and calibrated flight-test aircraft
- Loads Predictions = Well understood (e.g. wind tunnel derived)
- Flight Level = Methodical envelope expansion up to 100% DLL



Static Structures (Cont.)



- **Approach #1 (“No-Test & No-Data” Factor of Safety)**
 - Factor of Safety = 2.25 FS on ultimate
 - Proof Test = None
 - Instrumentation = No loads instrumentation
 - Loads Predictions = Well understood and conservative
 - Flight Level = 100% DLL



**AFTI/F-16XL2 Supersonic
Laminar Flow Control
Glove and Attachments**



G-III Adaptive Compliant Trailing Edge (ACTE)



**F-106/C-141 Tow Launch
Demonstration**



AFTI/F-111 MAW Cambered LE & TE

Static Structures (Cont.)



- **Approach #2 (“Test & Data” Factor of Safety)**

- Factor of Safety = 1.5 FS on ultimate
- Proof Test = 100% LL (Flight-test aircraft is proof test aircraft)
- Instrumentation = Fully instrumented and calibrated flight-test aircraft
- Loads Predictions = **Low confidence in loads**
- Flight Level = 80% LL (100% LL on a case-by-case basis)
- Proof test = 1.25 of flight limit → 1.875 equivalent design FS



Static Structures (Cont.)



- **Approach #3 (“Test & No-Data” Factor of Safety)**
 - Factor of Safety = 1.8 FS on ultimate
 - Proof Test = 120% LL (Flight-test aircraft is proof test aircraft)
 - Instrumentation = None
 - Loads Predictions = Well understood & conservative load predictions
 - Rarely have well understood & conservative load predictions
 - This approach often coupled with instrumentation to gain confidence in loads → Becomes like approach #2
 - Flight Level = 100% LL



Composites



• Building Block Approach for Experimental Flight

- Building block approach requires time and money but reduces risk (safety, technical, and programmatic)
- Impractical to test everything → Balance between analysis and test
- Testing supports analysis for critical and complex features
- Appropriately scope building block approach for prototype flight

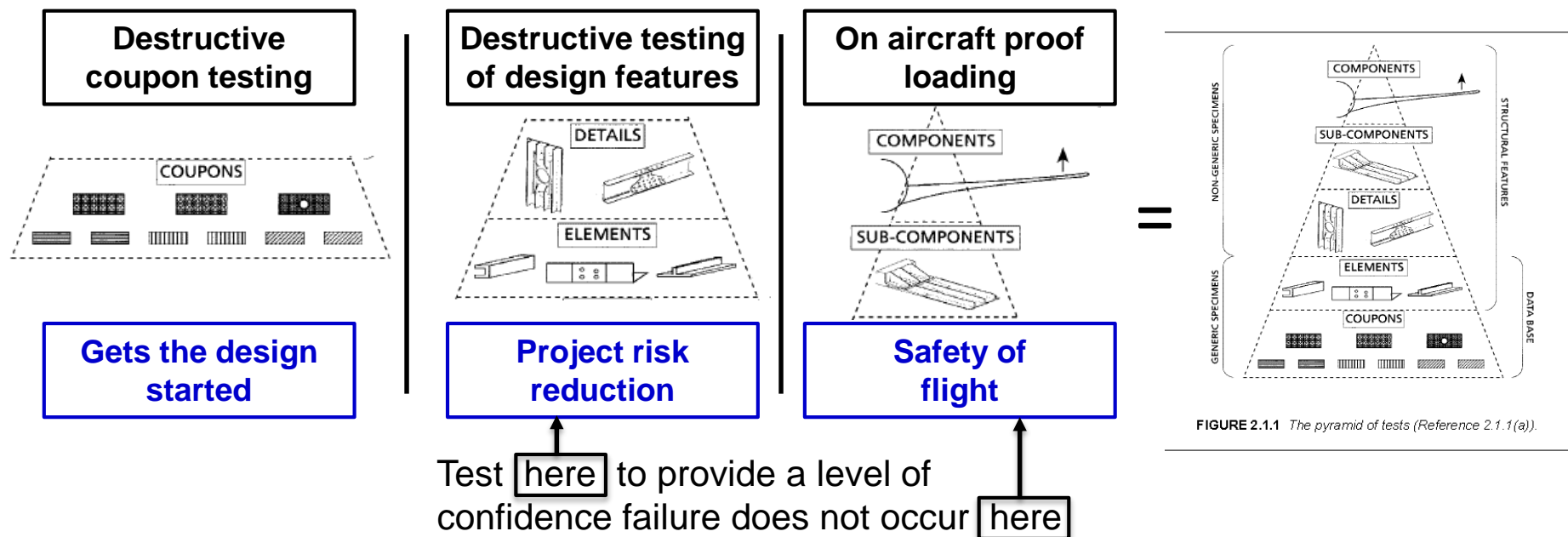


FIGURE 2.1.1 The pyramid of tests (Reference 2.1.1(a)).

Composites (Cont.)



- **Airworthiness requires close link between design, analysis, and manufacturing to understand “as built” performance**
 - Relationship easier to establish when working with high pedigree manufacturers with proven processes and ability to leverage design databases
 - Start-ups have a path to airworthiness at a cost of higher scrutiny
- **Many paths to airworthiness → Tailorable based on risk posture, design FS, test pedigree, M&P confidence, etc.**
- **AFRC best practices:**
 - If proven material equivalence, follow Static Structures approaches
 - FS=3.0 for secondary/tertiary structures with unknown equivalence

Aeroelasticity



- **Modified, previously-certified aircraft or new store or experiment carriage configurations**
- **Flutter Criteria: Minimum 15-20% margin on Equivalent Air Speed (EAS) and Mach Number**
- **AFRC process:**
 - Step #1: Gather historical aeroelastic information pertaining to aircraft/test article
 - Step #2: Choose clearance approach to show airworthiness = most efficient effort to provide sufficient evidence consistent w/risk posture
 - 1) Clearance by **flutter analysis, Ground Vibration Test (GVT)/Modal Test, and flight-testing**
 - Large margin ($\sim >100\%$) on high-confidence model, flutter testing normally not required
 - Low margin ($\sim <100\%$) on high-confidence model, flutter testing and/or monitoring may be required
 - 2) Clearance by **flutter sensitivity study**
 - 3) Clearance by **aeroelastic similarity**

Mainly used for smaller structural modification

Aeroelasticity (Cont.)



- **Approach #1 (Flutter analysis, GVT, and flight-test)**

- Standard approach for new aircraft/test article or previously certified aircraft with significant structural and/or mass modifications
- GVT data used to validate or update Finite Element Model (FEM) and aid in flight flutter testing
- Flutter analyses often conducted twice (depending on quality of FEM)
- Flight flutter testing proves no aeroelastic instabilities exist within planned flight envelope and to extrapolated flutter criteria



Aeroelasticity (Cont.)



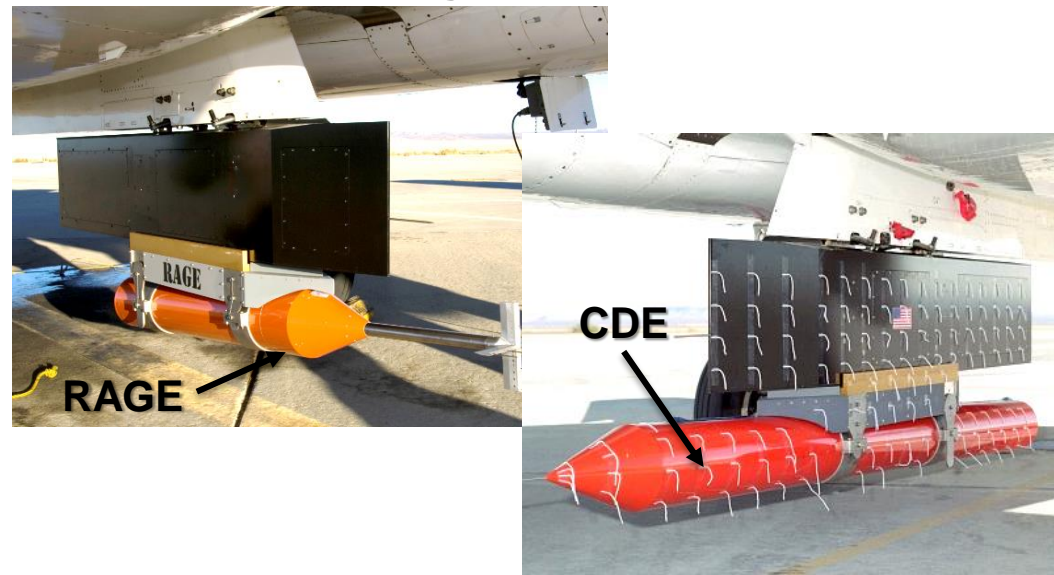
- **Approach #2 (Flutter sensitivity study)**

- When uncertainties in FEM parameters exist, flutter sensitivity study can capture variable combinations which bound the flutter envelope
 - Determine if large flutter margins exist with all variations
 - Identify flutter critical combinations & justify further investigation
- If necessary, perform limited GVT to validate FEM

DC-8 High Ice Water Content (HIWC) Wingtip Pylon



F-15B Rake Airflow Gage Experiment (RAGE) & Cone Drag Experiment (CDE) attached to Propulsion Flight Test Fixture (PFTF)



Aeroelasticity (Cont.)

• Approach #3 (Aeroelastic similarity)

- Minimum effort & low cost approach
- Often used for new external stores when previously cleared on same pylon and same aircraft location
 - Similar mass & stiffness distributions and unsteady aerodynamic forces as previous flown and cleared configuration
 - Often, stores considered stiff & treated as rigid-bodies attached to a flexible pylon; Shape, mass, CG location, & inertias of old and new stores may be sufficient for comparison

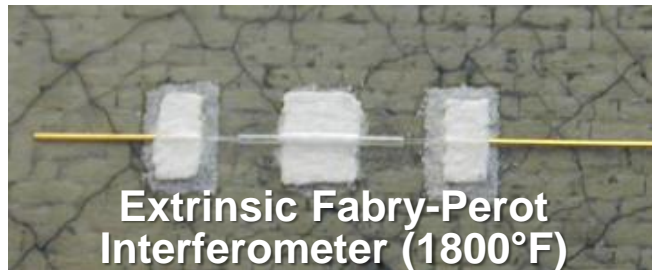
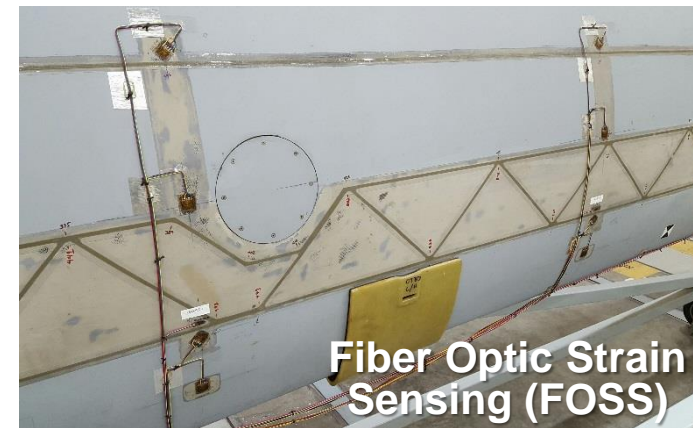
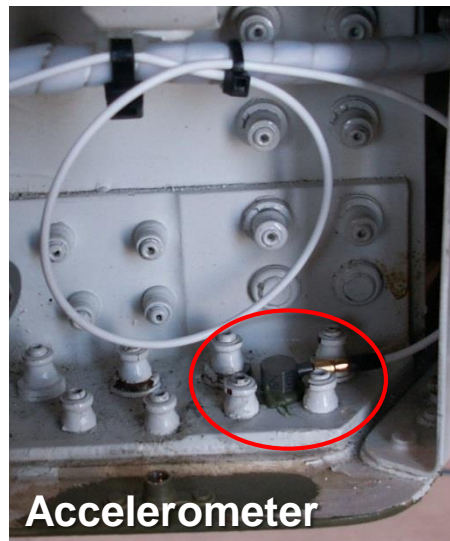
F-15B Aeronautics Research Testbed



Structural Instrumentation



- **Instrumentation required to understand performance...**
 - Safety
 - Experiment success
 - Experiment failure
- **Flight research requires a combination of COTS and unique purpose-developed instrumentation**



- **Early involvement critical to experiment success**

Structural Instrumentation (Cont.)



- Purposed and opportune → Need strategic view to develop measurement and test technologies/techniques as a priority for future X-planes

Strain gage loads measurement techniques on composites proven on HiMAT then utilized on X-29



Electro-optical Flight Deflection Measurement System (FDMS) developed for HiMAT then utilized on AFTI/F-111 MAW, X-29, and X-53 AAW



Highly Maneuverable Aircraft Technology (HiMAT) 1979-83

Summary



- **X-planes and modified vehicles for flight research require a unique perspective compared to fleet certified airframes**
- **Aerostructures Lessons Learned / Best Practices**
 - #1 – Understand tailorable/adequate airworthiness processes applicable to flight research
 - #2 – Modified structure requires special considerations (e.g. modified inspection plans)
 - #3 – Tailor Static Structures airworthiness methodology to gain confidence in strength and loads
 - #4 – Understand the use of composites in non-certified, research airframes
 - #5 – Tailor Aeroelasticity airworthiness methodology to gain confidence in flutter margins
 - #6 – Make sure you have the ability to learn the right information from the research; Work instrumentation early in development

